

Development of SiC Large Tapered Crystal Growth

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Project Duration: FY09 to FY11

DOE Vehicle Technologies Program

Advanced Power Electronics and Electric Machines Research

FY11 Kickoff Meeting

Oak Ridge National Laboratory

Oak Ridge, Tennessee

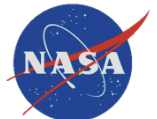
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Energy Efficiency &
Renewable Energy



*This presentation does not contain any
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The Problem

- Despite 20 years of development, majority of very large potential benefits of wide band gap semiconductor power electronics remain to be realized due in large part to high cost and high defect density of commercial SiC wafers.
- Commercial SiC power devices are significantly degraded (presently by factor of 2 in specific ON-state resistance) and power handling capability (current) is also limited due in part to the adverse effects of SiC crystal dislocation defects (thousands per cm^2) in the SiC wafer.

Project Overview

Research Focus Area: Power Electronics

→ *Temperature Tolerant Devices*

Objective

- Demonstrate initial feasibility of totally new “Large Tapered Crystal” (LTC) process for growing vastly improved large-diameter wide-band gap wafers.

Addresses Targets

- The goal of this research is to experimentally investigate and demonstrate feasibility of the key unproven LTC growth processes in SiC.
 - Laser-assisted growth of long SiC fiber seeds.
 - Radial epitaxial growth enlargement of seeds into large SiC boules.

Uniqueness and Impacts

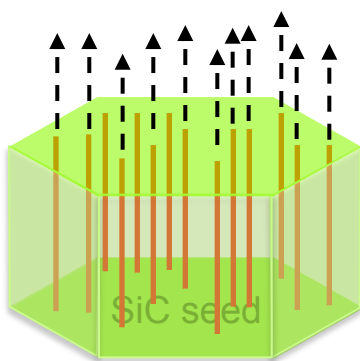
- Open a new technology path to large-diameter SiC and GaN wafers with **1000-fold defect density improvement at 2-4 fold lower cost.**
- Leapfrog improvement in wide band gap power device capability and cost.

Description of Technology/Approach

Large Tapered Crystal (LTC) SiC Growth

Present SiC Growth Process

(Vapor transport)



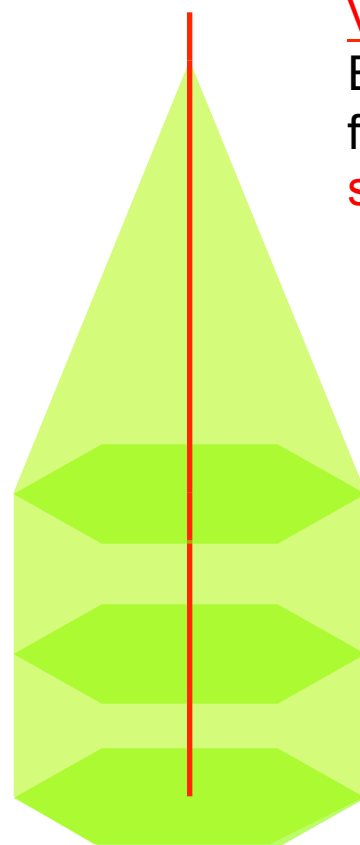
Vertical (c-axis) growth proceeds from top surface of large-area seed **via thousands of dislocations. (i.e., dislocation-mediated growth!)**

Crystal grown at $T > 2200\text{ }^{\circ}\text{C}$
High thermal gradient & stress.

Limited crystal thickness.

Proposed LTC Growth Process

(US Patent 7,449,065 OAI, Sest, NASA)



Vertical Growth Process:

Elongate small-diameter fiber seed grown from **single SiC dislocation.**

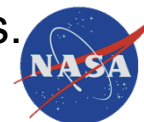
Lateral Growth Process:

CVD grow to enlarge fiber sidewalls into large boule.

- $1600\text{ }^{\circ}\text{C}$, lower stress
- Only 1 dislocation

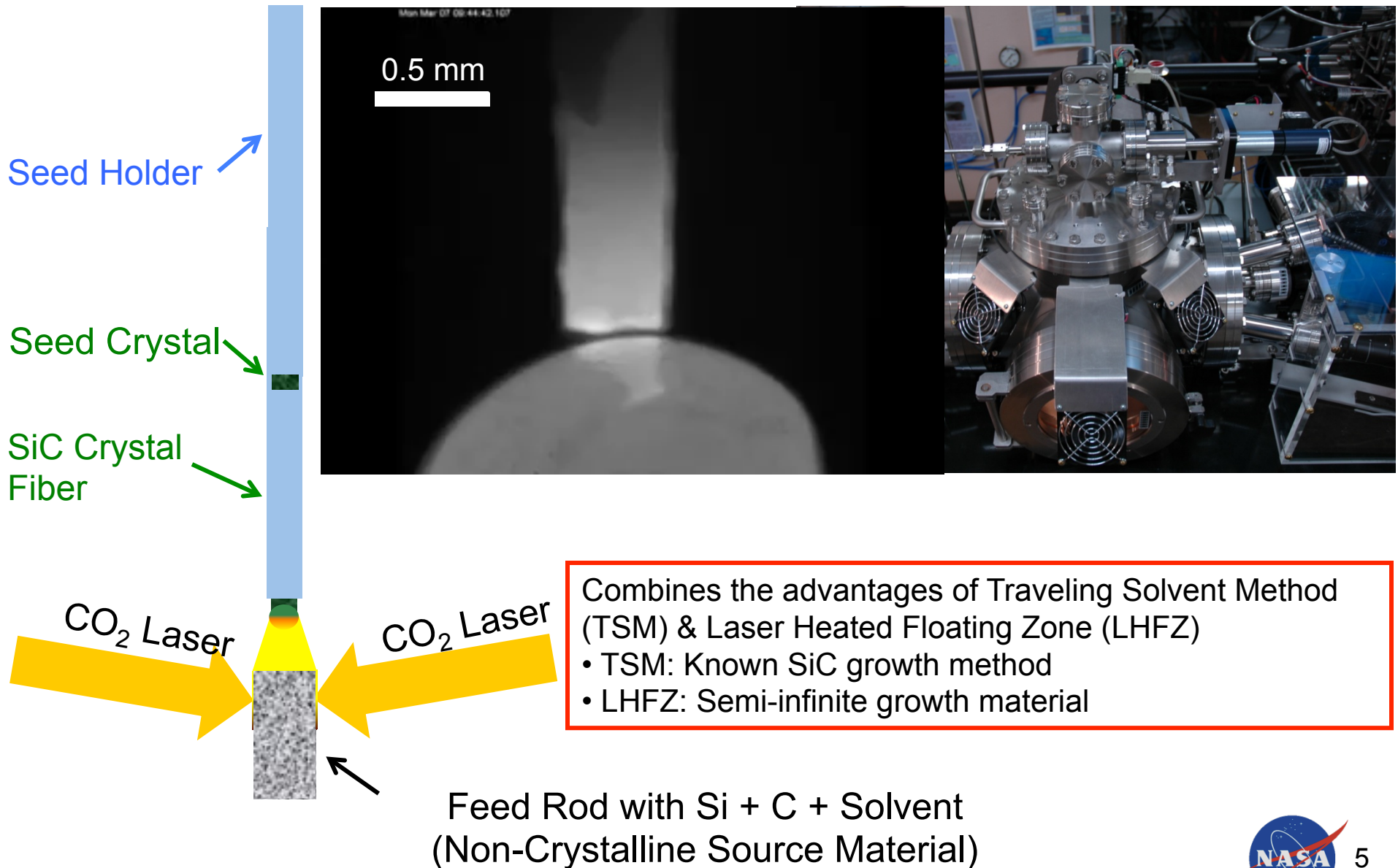
Lateral & **vertical** growth are simultaneous & continuous (creates tapered shape).

Radically change the SiC growth process geometry to enable full SiC benefit to power systems.



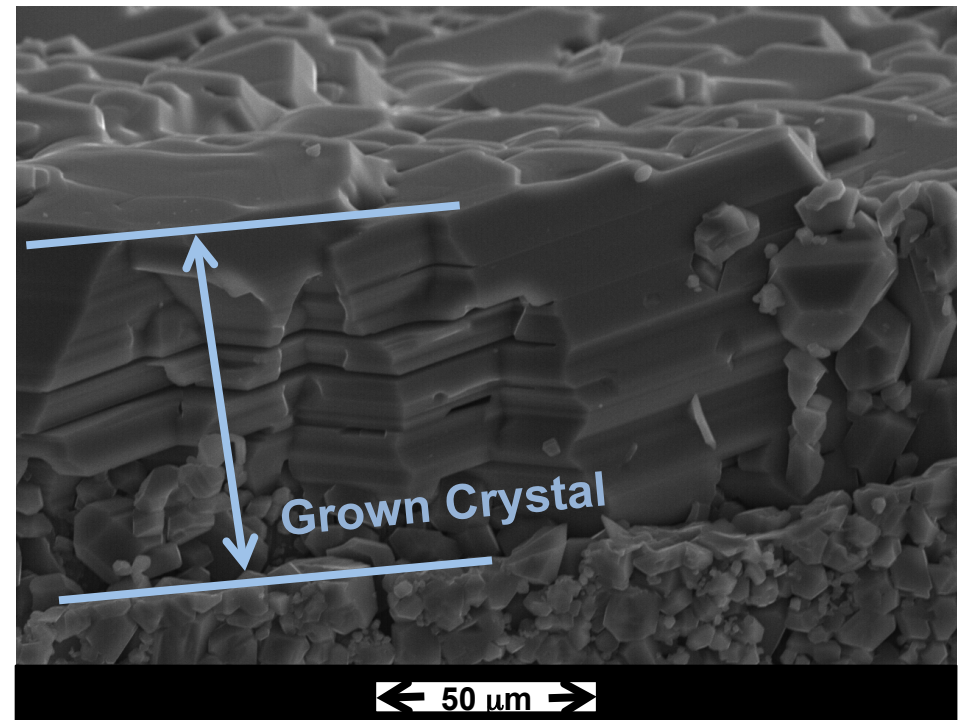
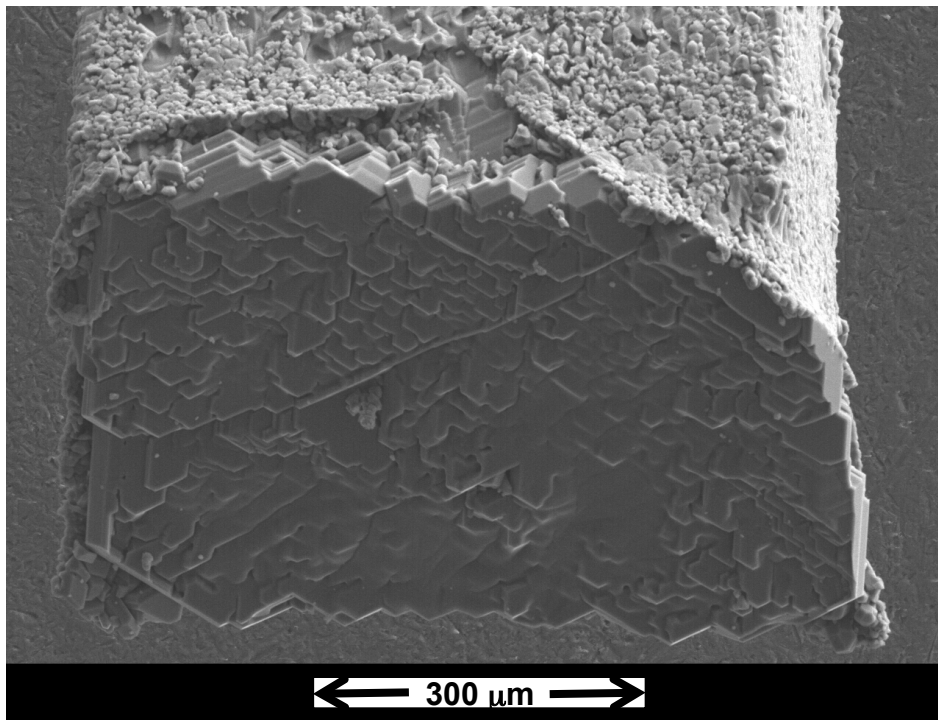
Description of Technology/Approach

(Solvent-LHFZ)- A New and Unique SiC fiber Growth Method



Accomplishments to Date (Solvent-LHFZ)

- 53 experimental runs since April 2011.
- Thick single crystal layers have been grown.
- Confirmed by synchrotron with beam topography (Prof. Dudley – Stony Brook U.).
- Presentation of results at ICSCRM 2011 (paper submitted).



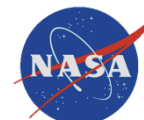
Accomplishments to Date (Solvent-LHFZ)

- Demonstrated control over growth rates
- Gained experience with different source material compositions
- Have achieved single crystal growth rates $>100 \mu\text{m}/\text{hour}$ (polycrystalline $> 400 \mu\text{m}/\text{hour}$)

Note: Temperatures not corrected for emissivity

Growth Rates ($\mu\text{m}/\text{hour}$)

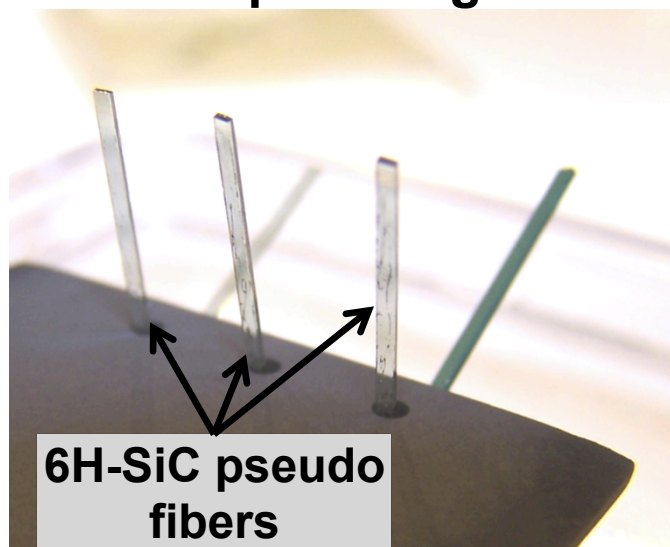
Fe/Si	C (at.%)	M.P. ($^{\circ}\text{C}$)	M.P.+90 $^{\circ}\text{C}$	M.P.+190 $^{\circ}\text{C}$	M.P.+325 $^{\circ}\text{C}$
Fe/Si~0.35	8	1170	4	40	135+
	16	1195	50	120	N/A
Fe/Si~1.9	8	N/A	No growth		



Accomplishments to Date (Lateral CVD)

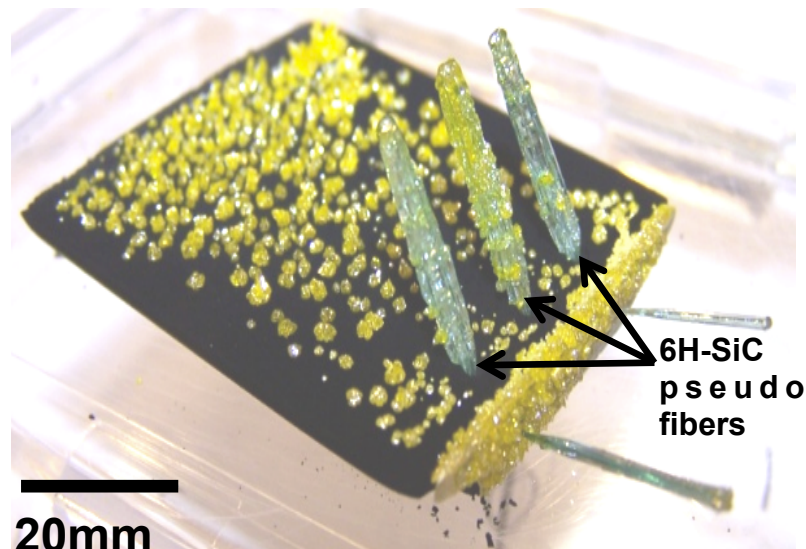
(25 CVD growth runs in modified hot wall CVD systems from April 1 to August 12, 2011)

**4H/6H SiC a/m-plane
slivers prior to growth**



- Pregrowth photo of slivers mounted on graphite carrier.

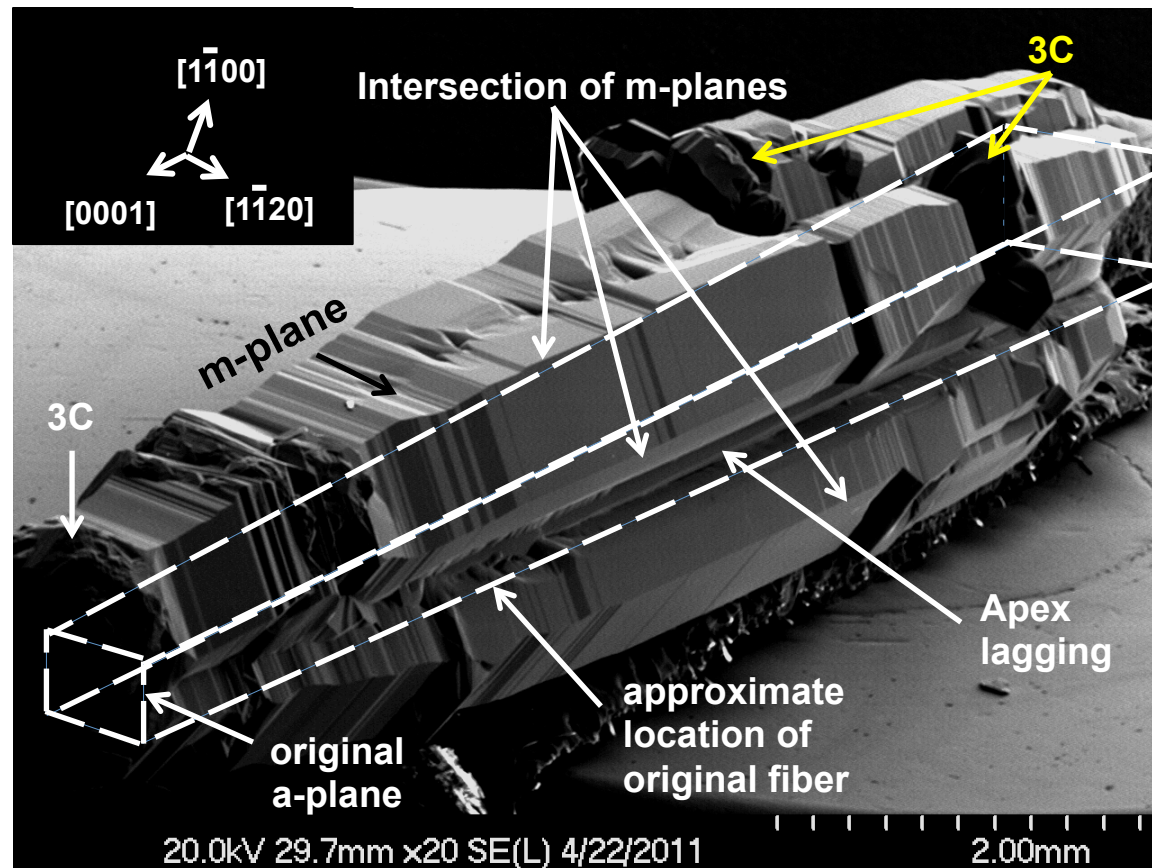
**Slivers after 8 hours of CVD
epitaxial growth**



- 20mm
- Post-growth crystals are translucent and exhibit lateral expansion (a/m-face growth).
- 3C-SiC crystallites (yellow) undesirably nucleated in some areas.

Accomplishments to Date (Lateral CVD)

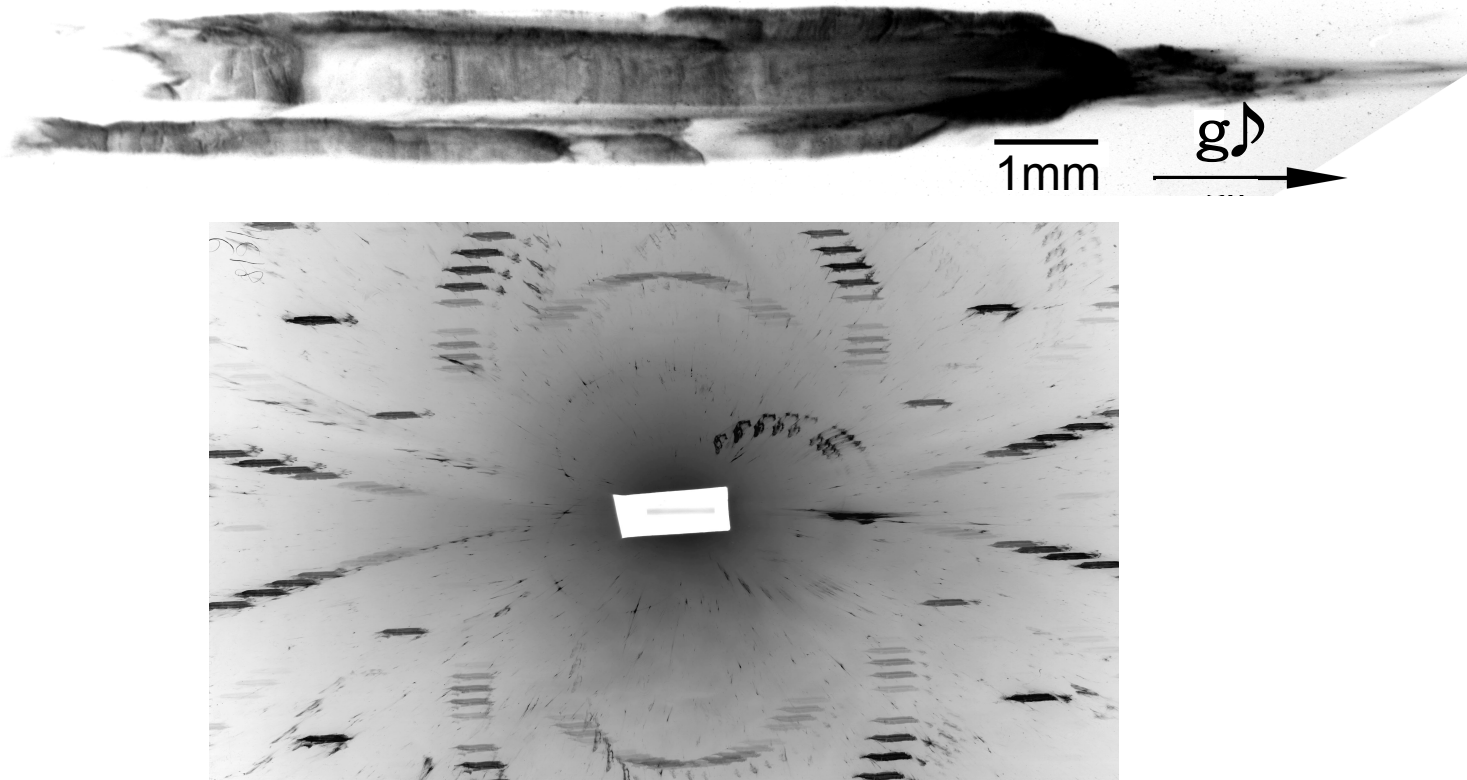
SEM of fiber after 8 hours of growth



- The sliver has increased in width by ~ 1.5 mm.
- The growth rate is ~ 180 $\mu\text{m/hr}$ in the a-axis direction (realized LTC goal!).
- Sliver is evolving towards hexagonal (crystal structure) shape.
- Results presented at ICSCRM 2011 (paper submitted).

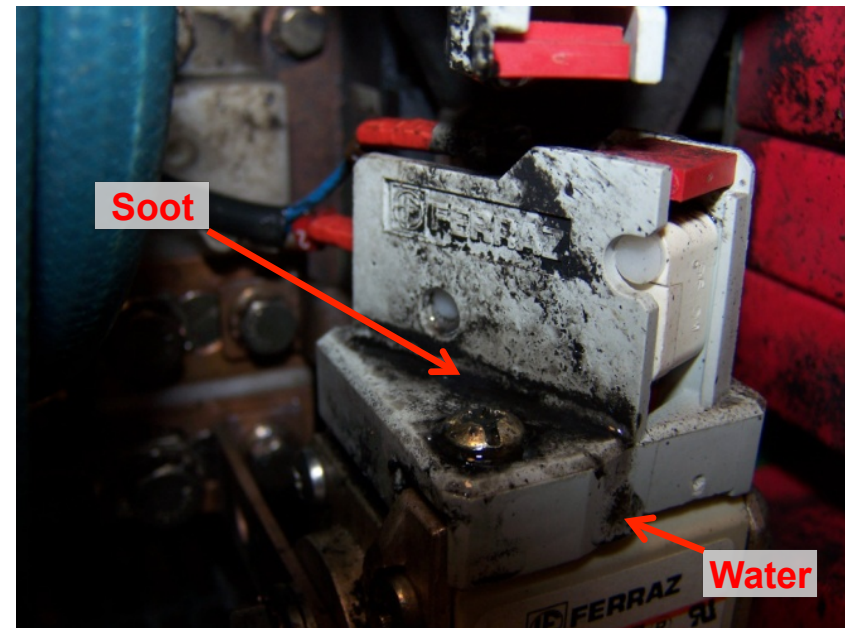
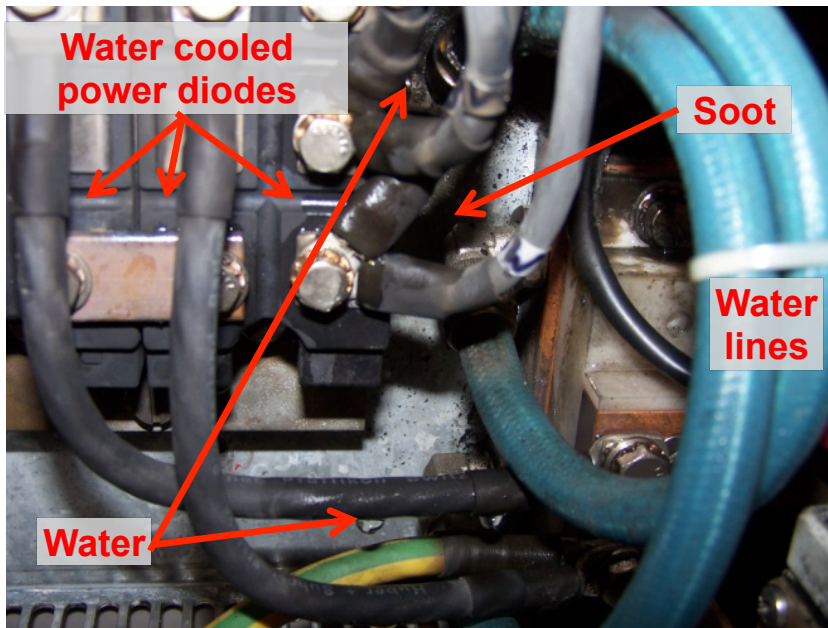
Accomplishments to Date (Lateral CVD)

Synchrotron white beam X-ray topograph (top) and diffraction pattern (bottom) of sliver after 8 hours of growth (from Prof. Dudley's group at Stony Brook U.)



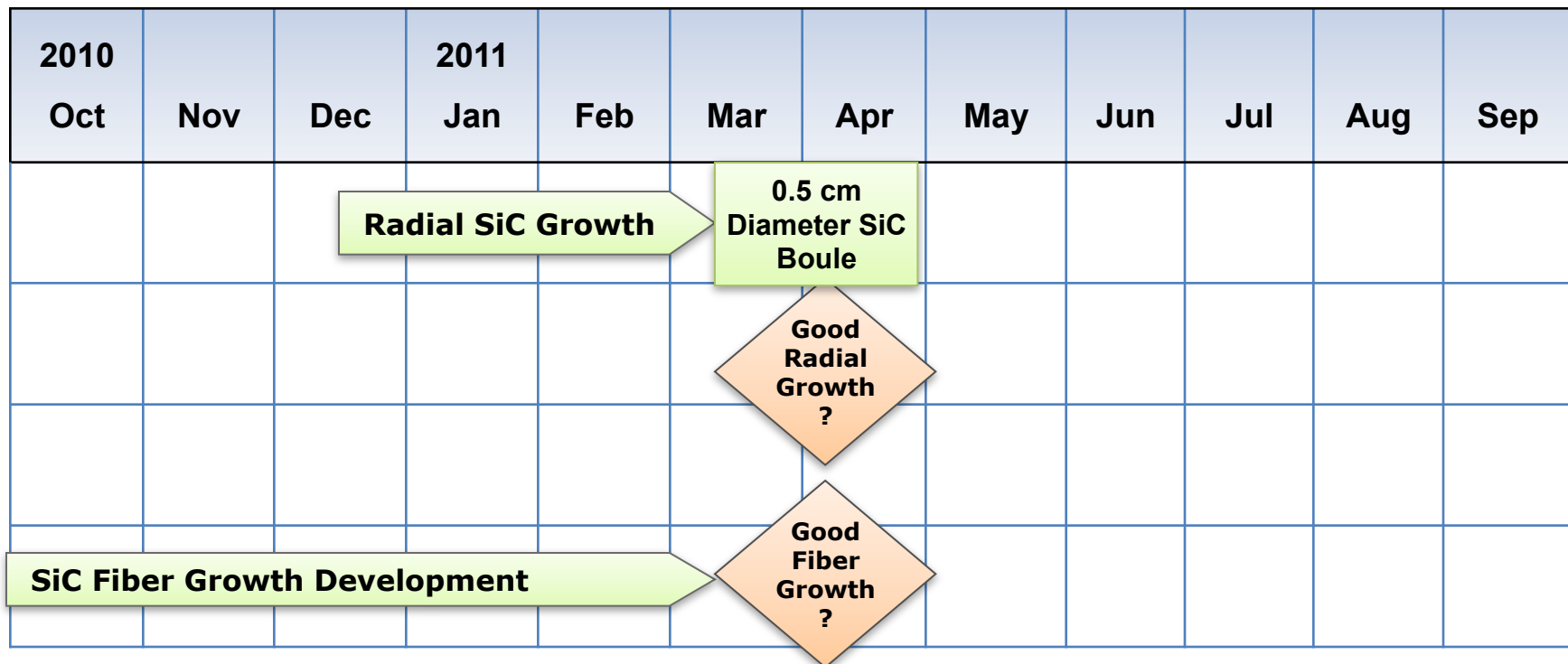
Confirmation of hexagonal polytype replication and low strain during CVD growth (for “clean” regions where parasitic 3C-SiC nucleation did not occur).

NASA Glenn SiC CVD Growth System Major Equipment Failure (RF Generator) on August 12, 2011



- Heavily damaged sub-system returned to manufacturer for replacement/repair.
- New RF generator has been ordered (using \$100K of NASA funds).
- **All lateral CVD SiC epitaxial growth work delayed until replacement generator is installed (January 2012?).**

FY12 Approach and Challenges



Go No/Go Decision Point: High quality SiC crystals (of proof-of-principle size) must be demonstrated for **both** radial and fiber growth processes.

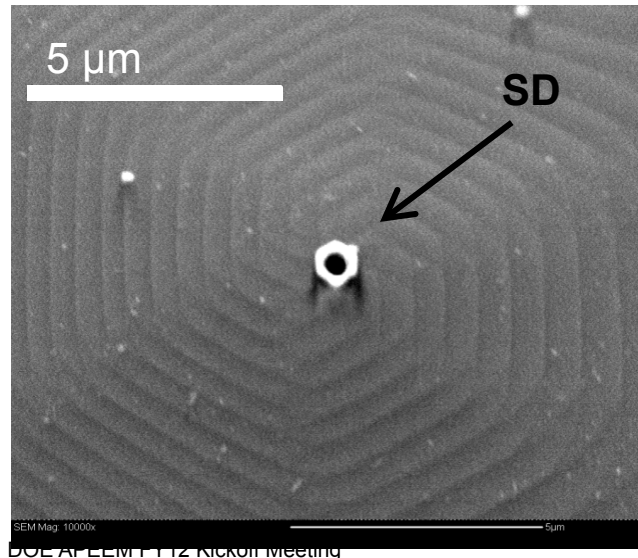
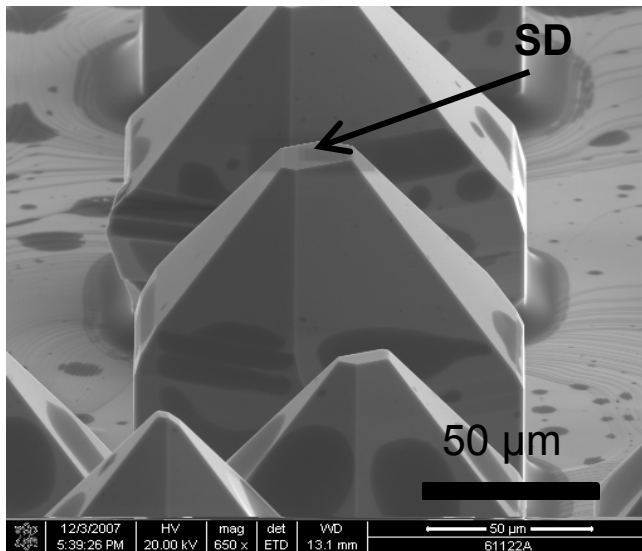
Challenges/Barriers: Both growth processes are “first ever” experimental demonstration attempts as methods of SiC growth.

FY12 Approach Highlights

- **Repair and resumption of lateral SiC epitaxy.**
- **Growth and characterization of milestone 0.5 cm diameter SiC boule (suppress 3C nucleation).**
- **Solvent LHFZ Growth of SiC fibers 10-fold longer SiC fiber**
- **Transition Solvent LHFZ experiments to micro-patterned mesa seed crystals.**
 - **Needed for well-ordered growth of much longer and narrower-diameter fibers.**
- **Timeline is major change – quantitative project metrics (i.e., demonstration crystal dimensions) will not be achieved within original 24-month project timeline (that ends December 2011).**

FY12 Approach Highlights (Solvent-LHFZ)

- Grow long polycrystalline fibers
- Initiate next generation seed crystal
 - Current seed crystals
 - Easy handling for initial Solvent-LHFZ experiments
 - Not suitable to grow long single crystal SiC fibers
 - Next generations seed crystals
 - Trap & utilize screw dislocation as crystal growth DNA
 - Smaller diameter -> faster ordered single-crystal growth



Beyond FY12 (Not in present agreement)

- Expansion of NASA Glenn resources for LTC SiC growth development are expected to initiate sometime during FY12. Should enable full completion of initial feasibility studies initiated under this Dept. of Energy Vehicle Technologies Program project funding.
- **FY13-14**
 - Once feasibility of lateral and fiber growth physics has been fully verified, launch joint development of full prototype LTC SiC growth system (fiber growth + lateral growth) in collaboration with commercial and/or university development partners.
 - Projected Go/No Go: High growth rate of nearly defect-free SiC boules & commercial investment.

Questions

